Application No.: 10/829,002
First Named Inventor: Buijsse Bart
Response to Office Action of October 18, 2005
Amendment Dated: January 18, 2006
Attorney Docket No.: FNL0303US

Remarks/Arguments

Claims 1-23 are in the application. Claims 1, 9, 19, and 21 are in independent form.

Objections to the Specification

The disclosure is objected to because the specification fails to include headers. Applicants submit a clean and a marked-up copy of a substitute specification that includes the requested headers.

Claim Rejections – 35 U.S.C. § 103

Claims 1-7 are rejected under 35 U.S.C. 103(a) as being unpatentable in view of U.S. Pat. No. 5,780,859 to Feuerbaum et al. ("Feuerbaum") and in view of U.S. Pat. No. 6,605,805 to Chen ("Chen").

The Examiner states that Feuerbaum teaches all the limitations of claim 1, with the exception of a permanent magnetic material for generating the focusing field, which is taught by Chen. Applicant submits that Feuerbaum does not teach "an electrostatic lens for producing a focusing electric field, in which the beam undergoes an energy change. . . characterized in that . . . said energy change has the form of an energy increase." Feurbaum teaches the opposite.

"This electrostatic lens has two electrodes held at different potentials, and these electrodes can have different potentials applied to them such that the charged particles, for example the electrons, are decelerated in the field of the electrostatic lens from a first energy to a lower second energy." Col. 2, lines 45-49. Chen explains why the energy of the electrons is typically reduced in the final objective lens. Some effects that tend to reduce resolution by broadening the electron beam, such as chromatic aberration and coulombic repulsion of electrons in the beam, are reduced by using a higher energy beam, but a high energy beam can damage the

specimen. Col. 1, line 63, to col. 2, line 19. Chen teaches that one way to reduce the aberration and avoid specimen damage is to use a beam that has a high energy through much of the optical column, and then using a retarding field to reduce the electron energy before the electrons strike the target. Col. 2, lines 25-26. The system described by Chen uses a retarding field. Abstract. Thus, both Chen and Feuerbaum teach an electrostatic field that decreases the energy of the beam, whereas claim 1 recites the opposite, an energy increase. Applicants submit therefore, that claim 1 is patentable over the cited references.

Moreover, the Examiner states that Chen teaches the desirability of a permanent magnetic material for generating a focusing magnetic field. Claim 1 is amended to clarify that a permanent magnet is used. Applicants submit that Chen does not teach the use of a permanent magnet. Chen teaches the use of an exciting coil 115, not a permanent magnet, to generate a magnetic filed, and a pole piece of a material that is "preferably iron, iron alloy, or other high permeability material for providing a low reluctance path for the magnetic field generated by the exciting coils 115." Col. 5, lines 4-7. Thus, the magnetic field is generated by exciting coil 115 and not by a permanent magnet. Applicant does not contend that the use of a permanent magnet in an electron lens is novel per se, but that the claimed configuration is novel and not obvious.

Claim 9 teaches "the magnetic lens and the electrostatic lens being configured such that the focal position of the lens assembly remains substantially constant as the energy of the charged particle beam is altered by the electrostatic lens." In a typical prior art charged particle beam system, changing the beam energy changes the focal length. If it is desired to maintain a beam focused on the same spot as the landing energy changes, the focusing power of the final lens is changed as the beam energy is changed. For example, Change states: "The reduced

energy of the primary beam needs to be taken into account when determining the strength of the magnetic field needed to focus the beam on the specimen." Col. 7, lines 59-62.

Applicants submit that all claims are now allowable and respectfully request reconsideration and allowance of the application.

Respectfully submitted,

Date: 1/18/06

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Particle-Optical Apparatus with a Permanent-Magnetic Lens and an Electrostatic Lens.

Field of the Invention

~~[1000]~~

[1000] The invention relates to a particle-optical apparatus provided with a focusing device having an optical axis for the purpose of focusing a beam of electrically charged particles upon a focus position, which focusing device comprises:

- a magnetic lens for producing a focusing magnetic field with the aid of magnetic pole pieces;
- an electrostatic lens for producing a focusing electric field, in which the beam undergoes an energy change,

whereby the focusing electric field is placed upstream with respect to a region situated between the focusing magnetic lens and the focus position.

Background of the Invention

[1001] Such an apparatus is known from US patent text No. 4,785,176.

[1002] Such apparatus are known inter alia as Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM) and Dual Beam Microscope (in which both an

ion beam and an electron beam are employed). Apparatus as described above are used nowadays inter alia in areas of development, inspection and production of, for example, ~~the semiconductor industry. In this context, both production means – such as lithographic~~ masks – and products and intermediate products – such as wafers – are inspected, repaired or manufactured in various phases using an electron beam and/or an ion beam. In irradiating a sample with charged particles, information can be obtained in various manners, such as with the aid of secondary particles and radiation excited in the sample. By collecting and processing this information with the aid of detectors, one can obtain insight into certain physical properties of the sample.

[1003] So as to prevent undesired electrical charging of, and/or damage to, the sample to be inspected, a certain landing energy will be required of the particles in the irradiating

[1004] beam, dependent upon the nature of the sample. In the case of inspection using electrons, the desired landing energy typically lies in the range 0.5 to 5 keV.

[1005] Because of the constitution of the sample can vary from location to location, it may be desirable to adjust the landing energy commensurate with this varying constitution. In that context, it is desirable that the focus position of the beam does not shift with respect to the focusing device. This is of particular importance in a production environment, such as during the inspection of wafers, where adjustment of the focusing would disadvantageously influence the production throughput.

[1006] ——The magnetic lens in such apparatus is usually embodied with a coil that, with

the aid of magnetic pole pieces, generates the focusing magnetic field. The current necessary for the generation of the magnetic field will cause heat dissipation in the coil.
The physical dimensioning of the magnetic lens is determined to a great extent by the size of the coil and the space required for any cooling means that might be present. These cooling means, such as a cooling-water spiral, may be required so as to limit undesirable consequences of the dissipation, such as mechanical changes arising from temperature changes in the pole pieces.

[1007] ——In the field of particle-optical apparatus, there is a desire to miniaturize focusing devices as described here, for example so as to create space for detectors, or, with the aid

of multiple beams of charged particles with attendant focusing devices, to concurrently obtain information from multiple locations on one or more samples.

[1008] ——In the US patent text referred to, a focusing device is described that consists of a magnetic lens for generating a focusing magnetic field with the aid of a coil and magnetic pole pieces, and an electrostatic lens for generating a focusing electric field, which electric field changes the energy of the beam. This known focusing device – by employing an electrostatic field that coincides wholly of partially with the magnetic field – strives to achieve a situation whereby the inevitable lens aberrations are smaller than the lens aberrations that can be achieved when using a magnetic lens alone. As regards the change in the energy of the beam, the US patent text referred to only states that the energy of the beam is decreased in the electrostatic field.

Summary of the Invention

[1009] The invention seeks to provide an apparatus of the sort described in the opening paragraph, in which the focus position – independent of the landing energy – has a fixed location with respect to the focusing device, and in which the focusing device is suitable for miniaturization.

[1010] To that end, the apparatus according to the invention is characterized in that the magnetic lens is provided with permanent-magnetic material for generating the focusing magnetic field required for the lens action, and said energy change has the form of an energy increase.

[1011] The use of permanent-magnetic materials leads, in the case of a given magnetic lens, to a constant magnetic field between the pole pieces, as a result of which different energies of the beam in the magnetic lens will result in different focal lengths of this lens.

[1012] The invention is based on the inventive insight that, if the energy change in the beam is an energy increase before or while the beam traverses the magnetic field of the magnetic lens, it becomes simple for the skilled artisan to construct the magnetic and electrostatic lens in such a manner that the changes in magnetic and electrostatic lens powers compensate one another. To this end, it is essential that the energy change be an energy increase, seeing as, in the case of a decrease in energy in the beam, both the electrostatic lens and the magnetic lens increase in power, so that, in this latter case, compensation cannot be achieved.

[1013] It is worth noting that the described scenario in the US patent text referred to does not offer this possibility, seeing as, in that scenario, only a decrease of the energy of the ~~beam is employed, for the purpose of achieving other goals as described therein.~~

[1014] In a preferential embodiment of the apparatus according to the invention, there is a region present around the optical axis in which region both a magnetic field and an electric field are present. Said measure implies that there is a region in which the electric field and the magnetic field overlap. As a result of this overlapping of the electric field and the magnetic field, a compact construction is made possible, born of the desire to miniaturize.

[1015] In another embodiment of the apparatus according to the invention, the sample-

side pole piece of the magnetic lens is made of electrically conductive material, and it

[1016] functions additionally as an electrode of the electrostatic lens. As a result of this integration of parts, a compact construction is made possible – born of the desire to miniaturize – and, in addition, the need to center the electrostatic electrode with respect to the magnetic pole piece becomes defunct.

[1017] In yet another embodiment of the apparatus according to the invention, the apparatus is provided with adjustment means for rendering adjustable the focus position that is to be held constant by the apparatus during imaging. This measure makes it possible to adjust the focus position to make allowances for irregularities in the sample in a situation in which the macroscopic position of the sample remains constant.

Brief Description of the Drawings

[1018] The invention will be elucidated on the basis of figures, in which identical reference numerals indicate corresponding elements. To this end:

[1019] Figure 1a is a schematic depiction of a focusing device for use in a particle-optical apparatus according to the invention;

[1020] Figure 1b is a graphic depiction of the distribution of the axial electric and magnetic field strength and the energy of the beam as occurring in the particle-optical apparatus as depicted in figure 1a;

[1021] Figure 2 is a schematic depiction of a focusing device for use in a particle-optical apparatus according to the invention.

Detailed Description of the Drawings

[1022] Figure 1a shows part of a particle-optical apparatus, such as a Scanning Electron

Microscope (SEM), according to the invention, whereby a beam 1 of electrically charged particles, such as a beam of electrons, moves along an optical axis 10 of the apparatus.

~~This beam 1 is focused upon a focus position 9 by a focusing device 11. It is~~ intended that

[1023] the focus position 9 be located upon a sample 8.

[1024] The focusing device 11 consists of a magnetic lens and an electrostatic lens. The magnetic lens consists of two pole pieces 4 and 5 and between which permanent-magnetic material 6 is located, whereby the pole pieces are separated by a gap 13 extending around the optical axis 10.

The electrostatic lens consists of two tube-like electrodes 2 and 3, located as a longitudinal extension of one another and around the optical axis 10, whereby electrode 3 is at earth potential and electrode 2 is connected to a power supply.

A coil 7 that is to be energized by an electrical current is located in the gap 13 between

[1025] the magnetic pole pieces 4 and 5.

Between the electrodes 2 and 3, a voltage difference is applied with the aid of the power

supply 12. This voltage difference causes a focusing electric field between the electrodes

[1026] 2 and 3. As a result of this focusing electric field, the beam 1 is accelerated to a certain energy – hereinafter referred to as the landing energy – with which the beam 1 impinges upon the sample 8.

[1027] The magnetic pole pieces 4 and 5 guide a magnetic flux generated by permanent-magnetic material 6 via the gap 13 to the region around the optical axis 10, where this flux causes a focusing magnetic field in the vicinity of the optical axis 10. To that end, when using the pole pieces 4 and 5 depicted in the figure, the permanent-magnetic material 6 has a magnetic direction parallel to the optical axis 10. The pole pieces 4 and 5 are dimensioned in such a manner that the scatter field due to the gap does not cause any significant magnetic field on, or in the vicinity of, the optical axis 10 exterior to the focusing device.

The additional magnetic field generated by coil 7 will, if desired, mildly change the

[1028] focusing magnetic field already present on the optical axis 10. The focusing ~~electric field~~

E on the optical axis 10, as generated by the electrostatic lens, is graphically depicted in figure 1b by curve 20. The focusing magnetic field B on the optical axis, as generated by the magnetic lens, is graphically depicted in figure 1b by curve 21. The energy U of the electrons in the beam 1 on the optical axis 10 is depicted in figure 1b by curve 22. In this configuration, the focusing electric field 20 and the focusing magnetic field 21 are partially mutually overlapping. No electric field is present in region 23 on the sample-side of the focusing magnetic field 21.

The focusing action of the focusing magnetic field 21 is determined inter alia by the

[1029] energy 22 with which the electrons in the beam 1 traverse the focusing magnetic field 21.

When the electrons in the beam 1 have a high energy at the location of the focusing

magnetic field 21, the focusing action will be less than the case whereby the electrons in

[1030] the beam 1 have a low energy at that location.

Since the energy of the beam 1 in the focusing magnetic field 21 is influenced by the

[1031] position and geometry of the focusing electric field 20, the choice of the location and geometry of the focusing electric field 20 with respect to the focusing magnetic field 21 can create a situation whereby changes in the magnetic and electrostatic lens powers compensate one another. As a result of this, as desired by the invention, the focus position 9 can be independent of the landing energy. Coil 7 can generate a magnetic field that can slightly change the focusing magnetic field 21 already present on the optical axis 10, for the purpose of adjusting the focus position 9 to make allowances for slight height variations of the sample 8, so that these slight height variations can be followed using the focused beam 1. The adjustment range of the focus position 9 is a slight fraction of the distance between pole piece 5 and the focus position 9. The magnetic field caused by the electrical coil 7 is thus a slight fraction of the focusing magnetic field 21 generated by the permanent-magnetic material 6. The current in the electrical coil 7 necessary to achieve the required adjustment range will thus be only a fraction of the current that would be necessary if the permanent-magnetic material were not present. The heat dissipation problem associated with the use of a lens coil is thereby virtually eliminated.

Figure 2 shows an apparatus that is virtually identical to the apparatus according to figure 1a, with the difference that electrode 3 is omitted in Figure 2, and the function of this electrode 3 is assumed by pole piece 5, which is now electrically earthed. In this

[1032] manner, the magnetic pole piece 5 also acts as an electrode of the electrostatic lens, and the focusing electric field is formed by the voltage difference between electrode 2 and pole piece 5. To that end, the magnetic pole piece 5 is made of electrically conductive material and is connected to earth potential. Simulations conducted on the basis of this embodiment have shown that, in this manner, a geometry can be found whereby – as desired by the invention – the focus position 9 can indeed be made independent of the

landing energy.